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DOUBLE SKIN BUILDING ENVELOPES AND THEIR IMPACT ON THE HVAC SYSTEMS AND ENERGY EFFICIENCY OF BUILDINGS

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ABSTRACT
Case studies are used to examine double skin building envelopes and their impact on the environmental control systems and energy efficiency of buildings. Double skin facades can improve building performance but also increase capital costs significantly. Therefore the economic viability depends not only on the potential to reduce energy costs but also on their potential to reduce the capital cost of the HVAC systems needed in the building. A mere reduction in the size of these systems will not lead to significant savings. However, if whole systems such as mechanical ventilation or conventional heating systems can be omitted due to the presence of a double façade, these savings can be offset against the increased costs and grey energy of the extra skin.

INTRODUCTION
Three case studies will be used to examine the implications of employing double skin envelopes. In the first building a double skin façade was used to alleviate common wind-related problems associated with high rise buildings, thus enabling natural ventilation for a greater part of the year and allowing the use of a quasi external shading device. The additional skin on the second building provides noise protection to enable opening windows despite traffic noise and is thermally so efficient, that a conventional heating system could be omitted. On the third project, the double skin envelope together with an optimised building form and a central atrium enables a tall building to be exclusively naturally ventilated, thus saving not only energy but also capital costs on the HVAC systems.

CASE STUDIES

GSW Headquarters Building, Berlin
By means of a 70 m high solar thermal convection façade the 22 office floors of the GSW-Tower can be naturally ventilated despite its urban location on a busy street intersection in Berlin. A double skin façade without any vertical or horizontal compartmentalization within the cavity provides natural exhaust of the offices used air by means of convection. The form of the roof construction at the top of the double skin façade was optimised to create a so-called venturi-effect at the top of the thermal flue, so that in addition to the thermal convection forces operating in the flue, wind forces are also harnessed to suck air out of the flue and aid the natural ventilation of the offices. The coloured blinds located in the cavity of the double skin façade provide quasi external solar shading. Outside air enters the building on the east side via motor controlled operable windows, flows through the offices and enters the double façade on the west side. The less dense warm air rises in the vertical facade cavity and pulls air through the offices. Exposed concrete slabs provide thermal mass. The windows, the

shading devices in the facade cavity and the dampers at the top and bottom of the facade are all automatically controlled via the Building Management System. The user can however override the control system at any time. On the floors where individual cellular offices are located, a transfer element in the partition wall allows air to circulate while providing sound protection between the offices and the corridor. In this building the windows are a component of the building ventilation system and needed to be designed and specified as such. With increasing height the pressure difference due to buoyancy decreases, so that the window openings need to increase in area on the upper floors. During construction, graphs were made based on laboratory measurements for each window type showing the relationship between the opening area, the pressure difference and the volume flow rate. The window openings were then adjusted during commissioning of the building using these graphs and the results of complex computer analysis of the natural ventilation system. The building is naturally ventilated for about 70 % of the year. When external conditions are extreme, a mechanical ventilation system is employed. In summer, cooling is via a desiccant cooling system which is regenerated by waste heat from the district heating system.

Braun Headquarters Building, Kronberg

In the architectural competition for the Braun Headquarters Building in Kronberg, Germany, a double skin façade on the building side facing the road was proposed, to enable natural ventilation despite the high external noise level due to traffic. During the development of the design it was decided to extend the double facade around all sides of the building. The reasons were twofold. On the one hand, the double skin envelope gave the optical appearance of a smooth glass façade while still retaining the benefits of a quasi external shading device. The second reason had to do with the thermal efficiency of a high performance double skin façade. If the thermal efficiency of the façade is sufficiently high, a conventional heating system can be dispensed with. In the Braun building a network of capillary tubing integrated into a thin plaster layer on the underside of the concrete slab, fed with warm water in cold weather and cool water in warm weather, is the only system needed to provide comfortable internal conditions in the offices. The fact, that a modern transparent office building can be conditioned with such minimal technology is attributable to the highly effective thermal performance of the building skin. An additional external skin is wrapped around the entire building. In the middle of the U-formed building plan a central atrium is formed via a PTFE foil cushion roof construction. A second glass skin with horizontal separations in the cavity at each floor and vertical separations at each façade planning module is employed on the external facades. Each module has an external window, which is automatically controlled and a narrow vertically aligned opaque element in the inside skin, which is manually operated for ventilation. The shading device is located in the cavity. The central atrium is an unheated buffer zone. Its roof can be completely opened in summer to allow unwanted heat to escape. Underground concrete ducts integrated into the building foundations supply tempered fresh air to the atrium. The outer skin of the building is automatically controlled via the building management system. The opening area of the skin is varied according to external conditions and the solar control blinds in the façade cavity are automatically adjusted depending on the degree of incident solar radiation. Artificial lighting is automatically adjusted depending on external light intensity. All settings can be overridden at any time by the users. The high performance of the building envelope means that the ceiling temperature is never heated above 27 °C or cooled below 20 °C. The concept not only reduced building energy consumption and offered improved comfort for the building users but also proved that the economical feasibility of double skin façades could be much improved compared to built buildings using these concepts to date. The effectiveness of the high-performance double skin façade allowed whole building systems, in this case the conventional heating system and the mechanical ventilation of the external offices to be completely dispensed with, und thus led to considerable capital cost savings on the buildings mechanical services. The building has been in use since 2000 and is very much liked by its users. The use of radiant systems, natural ventilation and high performance facades has led to internal conditions which by all accounts are very pleasant to work in.

European Central Bank New Headquarters, Frankfurt

The form of the new Headquarters Building for the ECB in Frankfurt was strongly influenced by strategies for maximising its energy performance and natural ventilating the offices. Two (in building energy performance terms) optimally orientated towers with their main facades facing north/south were placed on the site; positioned so, that an effective shading of the first tower is provided by the second. An additional skin was then wrapped around the two towers to create a central atrium and double skin facades on the external sides of the towers. The form and construction of the buildings were optimised, to employ wind, thermal and solar forces to provide controlled natural ventilation of the offices. The atrium facades are designed to act as wind scoops to channel wind into the atrium. In the external facades of the office towers the negative pressure at the specially designed "suction gaps" ensures that waste air is constantly drawn out of the building independent of the prevailing wind direction. Air flows from outside into the atrium and from there across the office floors before leaving the offices spaces on the external sides of the towers, thus ensuring effective cross ventilation of the office floors. The double façade on the external sides of the towers acts as a solar thermal exhaust flue. The less dense warmer air rises up through the flue and is replaced by cooler heavier air flowing through the office floors. On account of the height of the building, the façade is horizontally divided up into 3 sections with a height of approximately 50 m each, in order to keep the pressure differences between floors manageable. The solar shading devices are located in the cavity of the double façade, so that they are external to the space in a thermal sense but sheltered from wind and extreme weather by the outer skin. Exposed concrete ceilings in the offices provide thermal mass. The slabs are cooled via night time ventilation in warm weather, so that the cooling potential of the night air can be harnessed to provide radiant cooling during the occupied period. The slabs are also activated with a water system to cool the slabs in summer and heat in winter. A large portion of the annual energy required can be supplied by groundwater via energy piles integrated into the foundations. Meeting rooms are provided with fan coil units located in the floor void which, when operated, draw air directly from the atrium to provide forced ventilation with an air change rate to match the higher occupancy density. The proposed concept would make this building the first truly naturally ventilated modern skyscraper. All contemporary "naturally ventilated" high rise buildings of this height are in fact also provided with mechanical ventilation systems which are used in extreme weather conditions. This is however wasteful, as the systems thus provided need to be dimensioned for the worst case and are the same systems that would be provided in a sealed mechanically ventilated building with all the attendant disadvantages of increased capital costs and space required for shafts and plant rooms. The savings potential in maintenance and electrical energy costs is significant, particularly as the systems also tend to be used by the occupants at times when they were not designed to be.

ECONOMIC ASPECTS OF DOUBLE SKIN BUILDING ENVELOPES

In order to consider the economic aspects of double skin facades let us examine an office building with a typical office area per floor of 800 m² and a façade area per floor of 648 m². Assume the façade is a single skin double glazed construction and the offices are mechanically ventilated (2.5 air changes an hour). Let us assume that due to either noise or wind natural ventilation via opening windows is for the majority of the year not viable.

Reducing energy costs

The additional costs of a double-skin facade for this building are

$$€ (1200 - 900)/ m^2 \text{ façade} \times 648/ 800 = € 243/ m^2 \text{ office}$$

(assuming specific capital costs of € 1200/ m² façade for a double skin façade and € 900/ m² façade for a single-skin façade with a similar architectural appearance). If on account of the double skin, natural ventilation is now possible for say 70 % of the year, the resultant savings in energy costs are estimated to be

$$2 \text{ l/s} \times 3 \text{ W/ ls}^{-1} \times 2550 \text{ h} \times 0.12 \text{ €/ kWh} \times 10^{-3} \times 70\% = € 1.29 \text{ per m}^2 \text{ office and year}$$

(assuming a specific electrical energy consumption for supply and extract fans of 3 W per l/s, 2550 hours of operation a year and a specific cost of electrical energy = € 0.12/ kWh). The increased costs of cleaning the double skin façade need to be offset against this. Assume an additional annual cost of € 1 per m² façade (€ 0.81 per m² office). Estimation of the economic viability of the double skin option using the simple payback method yields a payback period of

$$243 / (1.29–0.81) = 506 \text{ years!}$$

This is of course a primitive method for calculating the payback period which does not take into account factors such as energy price increases etc. Nevertheless, the double skin is clearly not economically viable, at least not when calculated on this basis. Not included in the considerations above are the increased lighting and the reduced heating costs for the double-skin option. It is assumed that these practically cancel each other out. Cooling energy for both options is assumed to be approximately equal. While this is probably true for a low or medium rise building, if in a tall building, the double skin option allows the use of a quasi external shading device instead of internal blinds, there may be a marked reduction in cooling energy costs for the double skin option. Increased maintenance costs for the double skin façade have also not been taken into consideration.

If however the windows in the single skin façade cannot be opened on account of noise and/or wind, an increase in productivity as a result of improved occupant satisfaction due to opening windows may be associated with the double skin option. If we assume 10 m² office per user and a salary plus overhead cost of say € 12 000 per month per person, then a 1 % increase in productivity yields

$$(€ 12\,000 \times 12)/ 10 \text{ m}^2 \times 1\% = € 144/ \text{m}^2 \text{ office and year}$$

Our payback period now reduces to 243/ (144+1,29-0.81) = 1.7 years!

Omitting complete HVAC systems

If employing a double skin façade allows complete HVAC systems to be dispensed with, while still achieving comparable comfort conditions, the reduction in the capital costs of the

HVAC systems can be offset against the additional façade costs. In the case of the Braun building the additional cost of the double façade was estimated at € 250 per m² façade or roughly € 200 per m² office. The reduction in the capital costs of the HVAC systems were estimated to be in the order of € 150 per m² office area. The total additional capital costs are then € 50/ m² office, which amount to roughly 3 % of the total construction costs. The increased comfort and reduced energy costs here clearly ensure a payback period in a negligible time period.

If employing a double-skin façade on a high rise building such as proposed at the ECB headquarters building in Frankfurt means that the mechanical ventilation systems can be totally dispensed with, the resulting capital cost savings on the HVAC systems are

$$€\ 12/\ m^3\ h^{-1} \times 7.5\ m^3\ h^{-1} = €\ 90 \text{ per } m^2 \text{ office}$$

(assuming a specific capital cost of € 12 per m^3h^{-1} for a displacement ventilation system). Now consider the space saved on the plant rooms and shafts needed for the mechanical ventilation system. In a 20 storey building with a typical floor as described above, a shaft area of approx. 17 m² will be needed to accommodate the vertical distribution of the supply and extract ductwork. A central plant room with approx. 280 m² will also be required. If one assumes construction costs of € 2 500 per m² floor area this equates to

$$€\ 2\ 500/m^2 \times (280 + (20\times17))\ m^2 = €\ 1\ 550\ 000$$

or approx. € 97 per m² office. The total savings in capital costs are then approx. € 187 per m² office. If the annual maintenance, operation and repair costs for the mechanical ventilation system are assumed to be 5 % of the capital cost, then the resulting annual savings here are approx.

$$€\ 90 \times 5\% = €\ 4.5 \text{ per } m^2 \text{ office}$$

The savings on electrical energy consumed by the fans can be calculated as above and are in this case approx. € 1.84 per m² office. If we assume that the combined energy demand for heating, cooling and lighting for both options (i.e. single-skin façade with mechanical ventilation and double-skin façade without mechanical ventilation) are similar (research at our institute suggests this is broadly true), then we can calculate the payback period thus:

$$€\ (243-187)/\ (4.5+1.84-0.81) = 10 \text{ years}$$

ECOLOGICAL ASPECTS OF DOUBLE SKIN BUILDING ENVELOPES

The embodied energy associated with the additional skin on a typical double skin building envelope can be very roughly estimated as follows. Assuming a total thickness of 10 mm for the external glass layer and a glass density of 2500 kg/m³ gives a glass mass of approx. 25 kg/m² façade. For a double façade with maintenance walkways in the cavity assume that approx. 30 kg/m² façade of metal construction is also required. Assuming a value of 13 MJ/kg for glass and an average of 45 MJ/kg for the metal components the embodied energy is

$(25 \times 13) + (30\times45) = 1675$ MJ/ m² façade

which equates to approx. 465 kWh/m² façade or 377 kWh/m² office.

Estimating the embodied energy of the omitted HVAC systems is more difficult as there is little data available on this subject. However, if we assume that the primary embodied energy of an office building is 14 GJ/m² (1), that the building services proportion of this is about 30 % (2) and further that the proportion due to the mechanical ventilation is approx. 20 % of this (2), then the embodied energy of the mechanical ventilation system can be estimated as

$14\ GJ/m^2 \times 30\ \% \times 20\% \times 10^3 = 840\ MJ/\ m^2$ total floor area

which equates to roughly 1260 MJ/m² office or 350 kWh/m² office.

If we assume an annual energy saving of 15.9 kWh/m² a (see above), then the time taken to recoup the higher embodied energy of the double skin option is

$(377\text{-}350)/15.9 = 1.7$ years.

CONCLUSIONS

Double skin facades can improve building performance but also increase capital costs significantly. Their economic viability therefore depends not only on the potential to reduce energy costs but also on their potential to reduce the capital cost of HVAC systems needed in the building. A mere reduction in the size of these systems will not lead to significant savings. However, if whole systems such as mechanical ventilation or conventional heating systems can be omitted due to the presence of a double skin façade, these savings can be offset against the increased costs and grey energy of the extra skin. The potential for increased productivity associated with improved occupant satisfaction should also be considered. Double skin facades would appear to be especially suitable for applications such as tall buildings, noisy external environments, refurbishment projects or a combination of these.

ACKNOWLEDGEMENTS

Case Study:	GSW Berlin	Braun Kronberg	ECB Frankfurt
Client:	GSW	Braun AG	ECB
Architect:	Sauerbruch Hutton	Schneider + Schumacher	Coop Himmelb(l)au
Engineer:	Arup	Arup	Arup
Built:	1999	2000	2009 (estimated)

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